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RATON-CLAYTON AND OCATE VOLCANIC FIELDS

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Abstract.—The Raton-Clayton (RCVF) and Ocate Volcanic Fields (OVF) constitute the most significant late Cenozoic volcanic activity east of the Rocky Mountains. A salient characteristic of volcanic fields is the relatively low volumetric rates of eruption compared with major volcanic centers. The RCVF consists of about 125 vents and, including outlying portions, covers nearly 20,000 km^2. Rocks range from about 9 Ma to less than 60,000 yrs, yielding a recurrence rate of approximately 1.3 X 10^{-5} volcanic events per year. The RCVF can be divided into three main phases of volcanic activity: (1) Raton, which includes basalt flows and rhyodacite domes; (2) Clayton, which includes voluminous basalt flows and the Sierra Grande shield volcano; and (3) Capulin, which includes cinder cones and flows centered on Capulin Volcano National Monument. Although widely cited, the previous age estimate of less than 10,000 yrs for Capulin Volcano was based on an interpreted correlation, not an absolute date. Two dating techniques, the cosmogenic helium technique and the Ar-Ar technique indicate a date for Capulin of about 58,000 yrs. Three major series of lava flow units were erupted from Capulin, with the second and third series erupted from the base of the cone at the "boca". It is likely that the eruption of the boca flow altered the profile of Capulin, subsequently its symmetry was restored by continued building of the cone. The Ocate Volcanic Field consists of at least 16 flows and about 50 associated vents ranging in age from 8.34±0.50 Ma to 0.81±0.14 Ma. Like the RCVF, three major topographic levels of lava flows relate to three age groups: (1) older than 5 Ma, which includes flows capping mesas with surfaces around 3000m in elevation and an apparent E-W fissure line of vents near Wagon Mound; (2) 5-4 Ma, which includes most of the flows around Agua Fria; and (3) younger than 4 Ma, which includes the most abundant flows in the OVF and such vents as Cerrito Pelon, Cerro Negro, Cerro del Oro and Maxon Crater. Flows from Maxon flowed 90 km eastward along the canyon cut by the Mora River where they occur 100m below the rim of the canyon and 125m above the present level of the river. The youngest flows in the field were erupted from Cerro del Oro, in the central part of Charette Mesa, northwest of Wagon Mound.

INTRODUCTION

The Raton-Clayton volcanic field (RCVF) is the eastern-most Cenozoic volcanic field in the United States. To the east, Cenozoic volcanic rocks are not encountered at this latitude again until the mid-Atlantic ridge. The RCVF lies at the northeastern end of the "Jemez lineament", an alignment of volcanic fields extending from the Pinacate field of Mexico through Arizona and into New Mexico. The Jemez Lineament has been cited by some as a structural anomaly, a hot spot trace, or a chance alignment of disparate fields arising from different melting anomalies. The Ocate volcanic field (OVF) lies immediately to the southwest along the eastern foothills of the Sangre de Cristo Mountains. Together these two fields constitute the most significant late Cenozoic volcanic activity east of the Rocky Mountains.

This paper is intended to be a review of work by many researchers in both of these volcanic fields. The paper also summarizes and coalesces present knowledge about the fields and all dates acquired on rocks from these fields. Stormer, publishing in the 1970's; Nielsen and Dungan, O'Neill, O'Neill and Mehnert, and Staatz in the 1980's; and Sayre, et al., Scott, et al., and Stroud in the 1990's have all significantly increased our knowledge and understanding of these volcanic fields. Sayre, et al. (1995) and Stroud (1996), have fundamentally changed the "common knowledge" of the date for Capulin Volcano. Geologist/NPS Park Ranger Allyson Mathis collected material from the researchers cited above for presentations to Monument visitors during her work in the 1990's at Capulin Volcano National Monument (A. Mathis, unpublished manuscript and personal communication, 1997).

Both fields contain volcanic rocks categorized by several researchers using a range of petrologic classification schemes, since new classifications are favored each decade. In general, the petrologic classifications used in this article are from Scott et al. (1990), Nielson and Dungan, (1985), Phelps et al. (1983), and Stormer (1972). The rock names used here do not, therefore, reflect the current IUGS chemical classification scheme.

CHARACTERISTICS OF VOLCANIC FIELDS

The volcanic fields of late Cenozoic age throughout the southwest are distinctive individually, in terms of the details of petrology, timing of eruptions, size, and morphology of vents; but overall, they are all characterized by many small centers of eruption of fundamentally basaltic, but ranging to more silicic, compositions. Much of what we know about volcanic fields is petrologic and stratigraphic, but studies of basaltic volcanism in general within the past three decades (Connor and Conway, 2000) have begun to explore the processes of volcanic eruption (well-recorded within volcanic fields), individual vents, the lava flows which make up the bulk of their erupted volumes, and the overall significance of fields in terms of their relationship to regional structures and patterns, and rates of activity.

Perhaps a salient characteristic of volcanic fields is the relatively low volumetric rates of eruption compared with major volcanic centers (Crumpler et al., 1992). Rates of 10^{-3} km^3 per year are so characteristic as to be practically diagnostic. Currently these low rates within volcanic fields are seen as evidence for relatively small amounts of melting in the underlying mantle over extended periods on the order of hundreds of thousands to millions of years. In contrast to major volcanic centers and edifices, such rates are so low that residence time in any likely shallow magma reservoirs exceeds the cooling time for the magma bodies. As a result, the individual batches of magma produced must find their way to the surface, ultimately resulting in a series of isolated eruptions that are unrelated to surrounding eruptions in terms of the details of their petrology. It is likely that volcanic fields represent melt production within many small areas

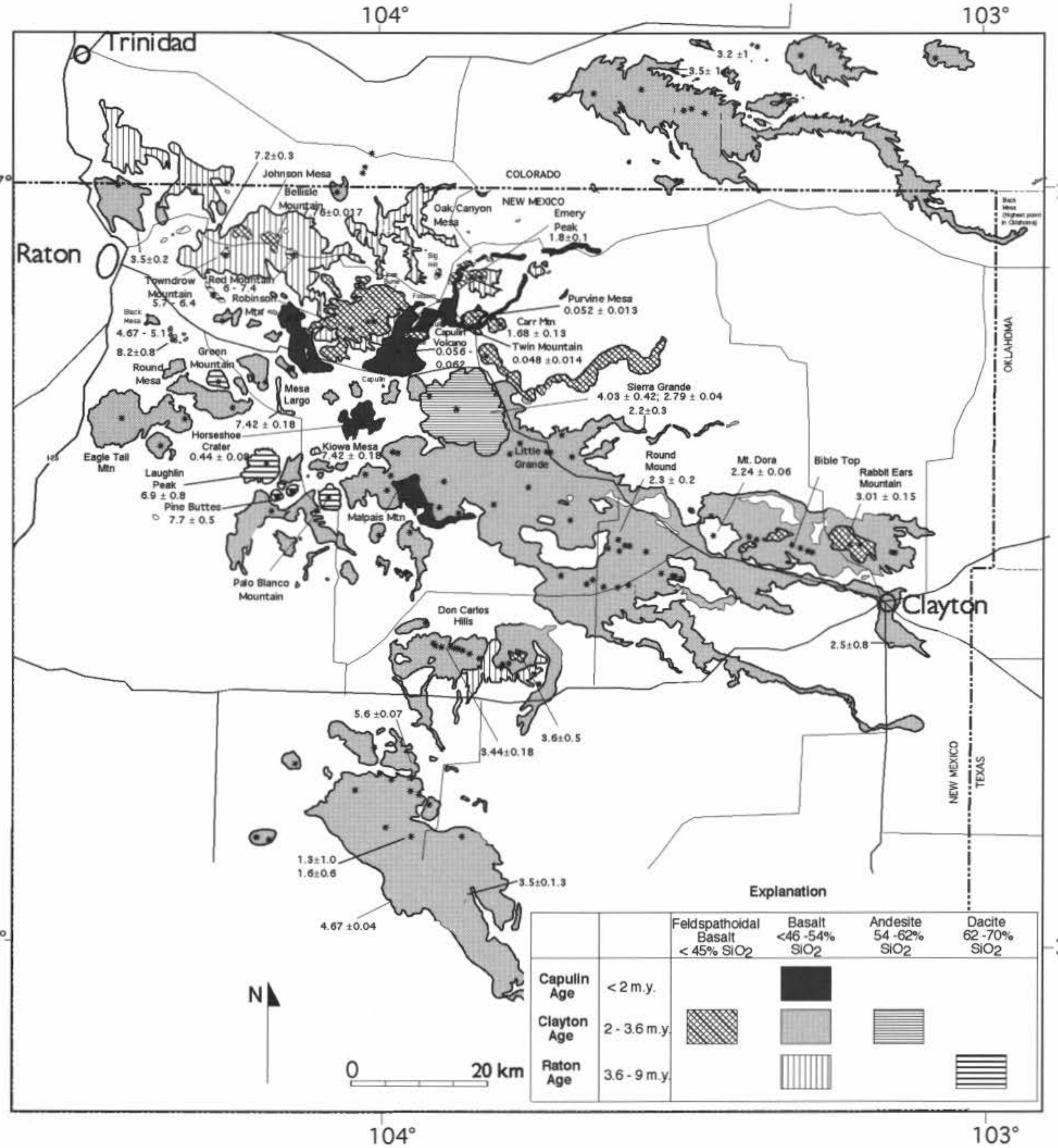

FIGURE 1. Geologic map of the Raton-Clayton volcanic field, showing the three principal phases of volcanism, the fundamental petrology and the currently known ages for volcanic units. Map redrafted with revisions after Luedke and Smith (1978).

of the regional mantle that are close to the solidus in response to regional thermal and local physiochemical anomalies.

RATON-CLAYTON VOLCANIC FIELD

The RCVF, delineated in Figure 1, consists of about 125 vents and extends from near Trinidad, Colorado, 140 km southeastward to Clayton, NM (Dungan, et al., 1989). Including outlying portions, the field covers nearly 20,000 km^2 (Stormer, 1987; Muehlberger et al., 1967). The oldest erupted rocks range from about 9 Ma and the youngest erupted less than 60,000 years ago (Sayre, et al., 1995; Stroud, 1996) (see Table 1), yielding a recurrence rate of approximately 1.3 x 10^{-5} volcanic events per year. Thus the eruption of Capulin over 60,000 years ago does not preclude future activity based on the overall recurrence intervals for the field as a whole.

One of the distinctive characteristics of the Raton-Clayton field is the presence of highly alkalic mafic lavas with SiO_2 contents as low as 36%, and ranging in composition from olivine melitite nephelinite to basanite (Gust, 1990; Phelps et al., 1983).

TABLE 1. Collected dates on rocks from the RCVF.

Name of Feature	Age (technique)	Reference
Raton Phase (9.0-3.6 Ma)		
Johnson Mesa	7.76 ± 0.017 Ma (Ar-Ar)	Stroud, 1996
Barrela Mesa	8.74 ± 0.04 Ma (Ar-Ar)	Stroud, 1996
Kiowa Mesa	7.42 ± 0.18 Ma (Ar-Ar)	Stroud, 1996
Mesa Larga	7.28 ±0.11 Ma (Ar-Ar)	Stroud, 1996
Mesa de Maya or Black Mesa	4.67-5.13 Ma (Ar-Ar)	Stroud, 1996
Red Mountain	6-7.4 Ma (K-Ar)	Scott, et al., 1990
	7.7-8.1 Ma (K-Ar)	Staatz, 1986, 1985
Dale Mountain	4.03 ± 0.12 Ma (Ar-Ar)	Stroud, 1996
Towndrow Peak	5.7-6.4 Ma (K-Ar)	Scott et al., 1990
Laughlin Peak	6.9 ± 0.80 Ma (K-Ar)	Scott et al., 1990
Pine Buttes	7.7 ± 0.5 Ma (K-Ar)	Scott et al., 1990
Kiowa Mesa	7.42 ± 0.18 Ma (Ar-Ar)	Stroud, 1996
Black Mesa	4.67 - 5.13 Ma (Ar-Ar)	Stroud, 1996
Mesa southeast of Black Mesa and north of Round Mesa	8.2 ± 0.8	Stormer, 1972
Clayton Phase (3.6 – 2.0Ma)		
Rabbit Ears Mountain	3.01 ± 0.15 Ma (Ar-Ar)	Stroud, 1996
Sierra Grande	4.0 – 2.6 Ma (Ar-Ar)	Stroud, 1996
Sierra Grande (base of NW flank)	1.9 ± 0.05 (Ar-Ar)	Stroud, 1996
Round Mound (Mt. Clayton)	2.3 ± 0.2 (Ar-Ar)	Stroud, 1996
Mt. Dora	2.24 ± 0.06 (Ar-Ar)	Stroud, 1996
Clayton basalt (distal end SE of Clayton)	2.5 ± 0.8 (Ar-Ar)	Stroud, 1996
Clayton basalt (east of Sierra Grande)	2.2 ± 0.3 (K-Ar)	Stormer, 1972
Don Carlos Hills	3.44 ± 0.18(K-Ar)	Stormer, 1972
	3.6 ± 0.5 (K-Ar)	
Southernmost vent	1.3 ± 1.0 (K-Ar)	Trauger, 1973
Roy flow	3.5 ± 1.3 (K-Ar)	Trauger, 1973
N. margin of Roy flow	5.62 ± 0.07	Stroud, 1996
S. margin of Roy flow	4.67± 0.04	Stroud, 1996
Clayton basalt in	3.5 ± 1.0 (K-Ar)	Hager, 1976
SE Colorado (extends into NM and OK)	3.2 ± 1.0 (K-Ar)	Hager, 1976
Capulin Phase (2.0-0.04 Ma)		
Horseshoe Crater	0.44 ± 0.08 Ma (Ar-Ar)	Stroud, 1996
Carr Mountain	1.68 ± 0.13 Ma (Ar-Ar)	Stroud, 1996
Emery Peak	1.8 Ma (Ar-Ar)	Stroud, 1996
Purvine Mesa	0.052 ± 0.13 Ma (Ar-Ar)	Stroud, 1996
Twin Mountain Mesa	0.048 ± 0.014 Ma (Ar-Ar)	Stroud, 1996
3rd flow unit, Capulin	0.225 ± 0.058 (Ar-Ar)	Stroud, 1996
5th flow unit, Capulin	0.056 ± 0.008 (Ar-Ar)	Stroud, 1996
Basalt in crater, Capulin	0.065 ± 0.049 (Ar-Ar)	Sayre et al., 1995
Boca, Capulin	0.050 ± 0.030 (Ar-Ar)	Stroud, 1996
Boca, Capulin	0.059 ± 0.006 Ma (3He:4He)	Sayre et al., 1995

Very few rocks of similar composition have been described from the Cenozoic volcanic fields of New Mexico. However, the field also contains centers, such as Sierra Grande, that erupted andesite, dacite or rhyodacite (up to nearly 70% SiO_2). Support for the probability of significant contamination in the petrogenesis of some of these rocks was suggested from the strontium isotope study by Jones et al. (1974).

Another distinctive characteristic of the field, and one it shares with the nearby Ocate Volcanic Field, is that the physiographic expressions of flows reflect their relative ages, with the oldest flows capping the highest mesas and the youngest flows following modern lowlands.

Phases of Volcanic Activity in the Raton-Clayton Volcanic Field

Traditionally, the RCVF has been divided into three main phases of volcanic activity (Baldwin and Muehlberger, 1959; Muehlberger et al., 1967; Calvin, 1987). These phases were initially determined by relative dating and compositional similarities. Although this fundamental sequence is still an appropriate model, the ages of these phases are now known to be older than previously believed based on new dates from Stroud (1996).

Raton Phase (9.0-3.6 Ma)

The Raton phase includes eruptions dated from 9.0 to 3.6 Ma (Stroud, 1996) and consists mostly of alkali olivine basalt lava flows and rhyodacite domes. The Raton age basalts are generally mesa-capping lava flows, which disconformably overlie the Paleocene Raton Formation and Cretaceous sandstones and shales, and reflect inverted topography. These include Johnson Mesa, Bartlett Mesa, Barrela Mesa, Horse Mesa, Kiowa Mesa, Mesa Larga, Mesa de Maya or Black Mesa and Kelleher Mesa.

Stroud (1996) investigated the erosion rates for the RCVF using the elevation difference between mesa tops and the local base area and estimating the rate of erosion with the assumption that erosion has been uniform since a flow's eruption. He found that erosion rates are greatest in the northwestern portion of the field (where many of the Raton age basalts are located) where erosion rates are as great as 115 m/Ma. In the east and central portions of the field, lava flows as old as 3.5 Ma have no significant erosional relief. This implies that, early in the RCVF history, uplift was occurring to the northwest.

The Raton-age Red Mountain rhyodacite, occurs as numerous volcanic domes in the western and central portion of the field (Scott and Pillmore, 1993); and includes volcanic centers such as Red Mountain, Towndrow Peak, Cunningham Butte, Green Mountain, Laughlin Peak, Raspberry Mountain, Pine Butte and Palo Blanco Mountain. Laughlin Peak is the only one of these eruptive centers that displays evidence for some pyroclastic activity. The vent edifice is primarily formed of rhyodacite vitrophyre flows and breccia, with a white rhyodacitic tuff found on the south flank (Staatz, 1985).

Between Laughlin Peak and Raspberry Mountain (porphyritic rhyodacite), in an area of approximately 12 km^2, occur many cross-cutting dikes and sills of different igneous composition and numerous thorium and rare-earth veins. The following description is from Staatz (1985). The veins lie along fracture zones and each consists of one large vein or a series of parallel smaller veins; the most common strike direction of the veins is parallel to that of the early faults in the region (between N30W and N80W). The suite of thorium and rare-earth minerals in these veins is unusual when compared with that of other thorium and rare-earth districts; in the Laughlin Peak area this suite consists of brockite, crandallite, and xenotime (all PO_4 minerals), and neither thorite nor monazite have been identified.

Clayton Phase (3.6-2.0 Ma)

The Clayton phase includes eruptions dated from 3.0 - 2.2 Ma (Stroud, 1996) and consists of three units: Clayton basalts (considered transitional olivine basalts by Dungan et al., 1989); basanites (such as Jose Butte and Robinson Peak); and the Sierra Grande andesite. The voluminous Clayton basalts encompass a number of eroded basaltic cinder cones or shield volcanoes that are located near Clayton, NM. These include Rabbit Ear Mountain, Bible Top Butte, and Sierra Clayton or Round Mound (all are cinder cones) and Mt Dora (or Cieneguilla del Burro Mountain) which is a shield volcano. The final eruption of the Clayton basalts was at Mt. Dora, dated at 2.24±0.06 Ma.

One of the greatest battles of Spanish New Mexico was fought near Rabbit Ear Mountain in 1717 between the Spanish and the Comanche; it was also the first "mountain" encountered by travelers on the Santa Fe trail as they approached the Rocky Mountains. Today, the basalt flows and vents of the extreme eastern margin of the field are still among the first visible sights that travelers on airline fights from Chicago to Albuquerque see as they enter New Mexico.

The easternmost edge of the RCVF is primarily dominated by Clayton age flows capping the sand and gravel of the Ogallalah Formation. For nearly the entire distance from Clayton to Des Moines, NM (named for the Iowa capitol), about 20 km, the highway is on Clayton age basalt flows for which this is the type area. The vent sources for these flows have not been positively identified, and may have come from vents in the central part of the field as well as from the eroded cinder cones in the eastern field.

Sierra Grande is an unusual volcano in that it most closely resembles a shield volcano in profile; and it consists almost entirely of 2-pyroxene (both clino- and orthopyroxene) andesite lava flows with compositions ranging from 60-62% SiO_2. Sierra Grande is the only eruptive center in the RCVF containing 2-pyroxene andesite. The volcano is about 10 km in diameter with a slope of about 8 degrees and a maximum elevation of 2650 m. Several small cinder cones are visible around its base. It is not a dome nor is it a true stratovolcano; the vent edifice can best be described as an andesite shield volcano. In this respect we believe that it is comparable to the large volcanoes of the Taos Plateau volcanic field, such as San Antonio Mountain and Ute Mountain, in which thick viscous lava flows dominate and very little pyroclastic material is evident. Stroud (1996) obtained 6 Ar-Ar dates from Sierra Grande; one returned an age of 4.03 ± 0.42 Ma, however the other 5 dates cluster between 2.88 and 2.41 Ma. An earlier K-Ar date of 1.9±0.05 was reported by Stormer (1972).

The outstanding example of a fissure eruption in this volcanic field are the Clayton-age Don Carlos Hills in southwestern Union County. As many as 16 individual vents have been identified along a line that extends about 22 km.

Capulin Phase (2.0-0.04 Ma)

The Capulin phase includes rocks dated from 1.7 - 0.05 Ma (Stroud, 1996) (although Luedke and Smith, 1978, using the originally interpreted Capulin date, use a cutoff of 0.01 for the beginning of the Capulin age). This phase primarily consists of olivine basalt to basaltic andesite erupted as cinder cones, late fissure flows, and at least one phreatomagmatic vent. The Capulin-age basalts are generally in the western and central portions of the field and occupy present day valley floors.

Carr Mountain (also known as Gaylord Mt.) and Emery Peak both represent Capulin-age feldspathoidal eruptions. Carr Mountain is classified as a nephelinite cinder cone with 35.9 % SiO_2. It is the most mafic/alkalic rock in the RCVF, with rocks that contain phenocrysts of hauyne, a rare mineral found only in highly ultramafic rocks. Capulin-age Purvine Mesa was formed by a fissure eruption; and Mud Hill is a phreatomagmatic tuff ring.

Capulin Volcano, Baby Capulin, Twin Mountain, Horseshoe Crater, The Crater, and Malpie Mountain are all basaltic andesite cinder cones. Relative ages based on field studies indicate that Mud Hill, Horseshoe Crater and Emery Peak pre-date Capulin, while Baby Capulin and Twin Peak post-date Capulin. Based on stratigraphic relationships of basalt flows, Baby Capulin may be the youngest vent in the field. Lava flows from Baby Capulin flowed about 10 km down the Dry Cimarron River.

Capulin Volcano

Capulin Volcano (*capulin* is Spanish for wild cherry or chokecherry— named for the bushes found in its sheltered crater) is the center of the most recent volcanic activity in the field. Recent work by Sayre et al. (1995), and Stroud (1996) has resulted in new dates indicating that Capulin erupted approximately 56,000 to 62,000 yrs B.P., somewhat older than the reported age of the famed Folsom paleosite (11,000 yrs B.P.) on which an earlier relative stratigraphic date was based.

Although widely cited, the previous age estimate of less than 10,000 years for the eruption of Capulin Volcano was obtained through an interpreted correlation of a Capulin lava flow unit with alluvium layers believed to be associated with the Folsom archaeological site. At the Folsom site, ^{14}C determinations were made on charcoal and bison bones within two layers of alluvium (Muehlberger, 1955; Anderson and Haynes, 1978; and Haynes et al., 1992). Nine miles from the Folsom site, a Capulin Volcano flow occurs between two alluvial deposits and Muehlberger (1955) interpreted these alluvium layers to be contiguous with the Folsom layers. Therefore, the Capulin eruption was assigned an age range between approximately 10,000 and 4,000 yrs B.P. (the average ^{14}C dates for the layers). Subsequent work (Anderson and Haynes, 1978) identified several distinct alluvial deposits and concluded that the basalt flow overlies an older alluvial sequence with a minimum age of 22,360 ± 1,160 yrs B.P.

Prior to 1995, no absolute age determinations existed for rocks from Capulin Volcano. In 1995 and 1996, two different techniques were used. Sayre et al. (1995) determined the age of a sample of Capulin basalt using the cosmogenic helium technique. This dating technique provides information on how long a rock sample has been within 1m of Earth's surface; and therefore is a useful technique for dating young volcanic flow units. Cosmic rays produce ^3He, normally a very scarce isotope, at a steady, known rate at the Earth's surface. The ^3He:^4He ratio is then used to determine the amount of time a rock surface has been exposed to the atmosphere, with a correction for altitude and latitude. Careful sampling is required to find a sample that has been at the surface in its present orientation since cooling. At Capulin, a sample was collected from the flow at the boca (a late-eruption site at the base of the cone). The results indicate that this late Capulin flow is 59,000 ± 6,000 yrs. Stroud (1996) used the Ar-Ar technique to date four samples from various locations on Capulin which yielded a weighted average of 58,000 ± 4,000 yrs. The Ar-Ar technique is analytically difficult for this flow due to its young age and abundant crustal and mantle xenoliths. It is encouraging that both techniques yielded comparable dates. The new dates are consistent with the apparent state of erosion of cones of similar age throughout the Southwest.

Capulin is a classic cinder cone with associated volumes of lava flows. The crater rim is approximately 1.7 km in circumference and stands 305 m high, with a crater depth of 125 m. Based on a recent detailed study (M. Ort, unpublished map and manuscript, 1997; W.O. Sayer and M. Ort, unpublished report for the National Park Service, 1999), a complicated series of lava flow units and cinder/spatter eruptions occurred during and after eruption of the cinder cone. Three major series of lava flow units erupted, the earliest flowed to the east-southeast of the cone, the second to the west and south, and the third to the west and north. The second and third series of flows were erupted from an area at the base of the cone called the boca ("mouth" in Spanish). During these eruptions several intermittent lava lakes formed at the lower flanks of the volcano and portions of the cone were "rafted" away on the surface of the flows.

Cinder Cone Formation

Cinder cones like Capulin form through explosive fragmentation of basaltic magma as it emerges at the surface. Both CO_2 and H_2O vapor are the most common gases in magmas, requiring less than 1% of the gas to cause dispersal of magma. The type of pyroclastic activity that results in cinder cone formation, known as "strombolian" from the type example Stromboli in Italy, is characterized by "fire fountains" of pyroclasts that may rise up to a thousand feet in the air. The shape of cinder cones reflects more than just a rubble pile, but is distinctive and defined by a well-organized interior bedding and structure. This structure results from the accumulation of ash and cinder in specific ways during strombolian eruptions. The thermal structure within the fire fountain (Head and Wilson, 1989) favors the deposition of fluid spatter, rootless flows, and welded cinder near the vent, and more rubble-like solid cinder and ash at greater distances. Both of these types of deposits may be seen at Capulin volcano. The erupted clasts follow ballistic, and characteristically parabolic, trajectories; and there is a spread in angle of eruption and therefore distance that the clasts travel. Thus, the accumulation of material tends to form a pile that is initially round. As the eruption continues, a number of things can happen to destroy this symmetry. For example, the low strength of the cone flanks insure that any significant increase in effusion within the shallow feeder conduit and summit crater may result in lateral collapse of the cone flanks resulting in a breached crater profile. For this reason, perfect cones like Capulin are rare. It is likely that the formation of the Boca flow significantly altered the profile of Capulin volcano during its eruption, resulting in displacement of the western cone flanks. Continued building of the cone, following this event, restored the cone symmetry more or less, although our detailed morphometric and structural analysis shows that the cone-like morphology is slightly skewed implying that the Strombolian vent migrated slightly to the west following the catastrophic breaching. An interesting feature of many of the cinder/spatter vents in the RCVF, including Capulin, is that the craters open to the southwest or west; suggesting a prevailing southwesterly to westerly wind direction during eruption and accumulation of the pyroclastic ash and cinder. This would also have the effect of making the southwest and west flanks (since they were lower) more susceptible to breaching and collapse.

Chico Sill Complex

Although the most prominent geomorphic features of the RCVF are the cinder/spatter cones, domes, and flows of the Raton, Clayton and Capulin age eruptions; the oldest dated igneous rocks in the region are from 37 to 20 Ma and occur in the Chico sill complex. The following description is from Scott et al. (1990). The Chico sill complex occupies a broad domical area, with an exposed area of about 363 km^2, in the southeastern part of the field between Raton and Eagle Tail Mesa. Cretaceous rocks have been arched upward nearly 300 m by the intrusion of many tabular sills of predominantly alkalic trachyte and phonolite. Several diatremes have also been found, one just east of Raton has been dated at 30 Ma. West of Cimarron a laccolithic intrusion, about 29 Ma, intrudes upper Cretaceous rocks. Mafic dikes are common from Raton southward and vary in age from 24 Ma to possibly as young as 5 Ma.

Turkey Mountains

Other areas of doming by probable igneous intrusions of comparable age to the Chico sill complex lie near and west of Cimarron, and form the Turkey Mountains 11 km west of Wagon Mound. Near Cimarron, numerous sills suggest the presence of a large subsurface intrusion that some workers have suggested is related to the Latir Peak volcanic field (Scott et al., 1990). The Turkey Mountains form a "bulls-eye" of uplifted sedimentary rock units and are clearly the result of the intrusion of a laccolith. Outcrops of syenite at the summit area of the Turkey Mountains have been dated at 29.0 ± 1/6 Ma using the zircon fission-track method (Scott at al., 1990).

OCATE VOLCANIC FIELD

Introduction

The Ocate Volcanic Field (OVF) (sometimes called Mora volcanic field) is located at the boundary between the Southern Rocky Mountains and the Great Plains physiographic provinces; and lies on the east flank of the Rio Grande rift (Fig. 2). The field consists of at least 16 basaltic to dacitic flows and about 50 associated vents ranging in age from late Miocene to Pleistocene (over an 8 million year period) (see Table 2). Regional uplift and subsequent erosion, as in the western RCVF, has resulted in inverted topography where the oldest lava flows occupy the highest local elevation and younger flows cap successively lower mesas. Three major levels of lava flow-capped mesas decrease in elevation from west to east. O'Neill and Mehnert (1988) therefore discuss the activity of the OVF in three age groups: older than 5 Ma; between 5 and 4 Ma; and younger than 4 Ma. The oldest flows are underlain by stream gravels and appear to define a single surface cut into the interior of the Sangre de Cristo Mountains during late Miocene time. This surface cuts across major Laramide structures. Subsequent episodic uplift and erosion marked at least three lower erosional surfaces capped by flows dated between 4.8-4.1Ma, 3.3-3.1Ma. and 2.2Ma. Of these three later surfaces, the oldest is truncated and warped, probably due to uplift of the Cimarron block with respect to the adjacent great Plains (O'Neill, 1988)

Based on geochemical and petrographic data, Nielsen and Dungan (1985) defined five major rock types for the OVF: alkali olivine basalt, transitional olivine-basalt, xenocrystic basaltic andesite, olivine andesite, and dacite. O'Neill and Mehnert (1988) grouped all of the volcanic rocks into two major groups: typical flood basalts from low-profile shield volcanoes and fissures; and alkali basalt, andesite, dacite and nepheline-normative basalt from shield volcanoes and composite cones.

The OVF extends from the southern part of the Cimarron Range of the Sangre de Cristo Mountains southeastward to the general vicinity of Wagon Mound, NM. Flows from the field extend as far south as, and partially surround, the Turkey Mountains. Flows from source vents, such as Maxon Crater (shown as Maxson Crater on topographic maps), southeast of the Turkey Mountains, flowed eastward following the modern drainage of the Mora and Canadian Rivers for some distance. The following description of the three age groups is from O'Neill and Mehnert (1988).

Volcanism older than 5 Ma

Volcanic rocks of the oldest age group cap the highest gravel-covered surfaces. The oldest dated flows were erupted 8.3 Ma in the northwestern part of the field. Remnants cap Sierra Montuosa Mesa and La Grulla Ridge (both are slightly over 3000m in elevation). Slightly younger flows (between 5 and 6 Ma) erupted from widely separated vents near Wagon Mound and along the west side of the field. The vents near Wagon Mound, on Jarosa and Santa Clara Mesas west of I-25 and Las Mesas del Conjelon,

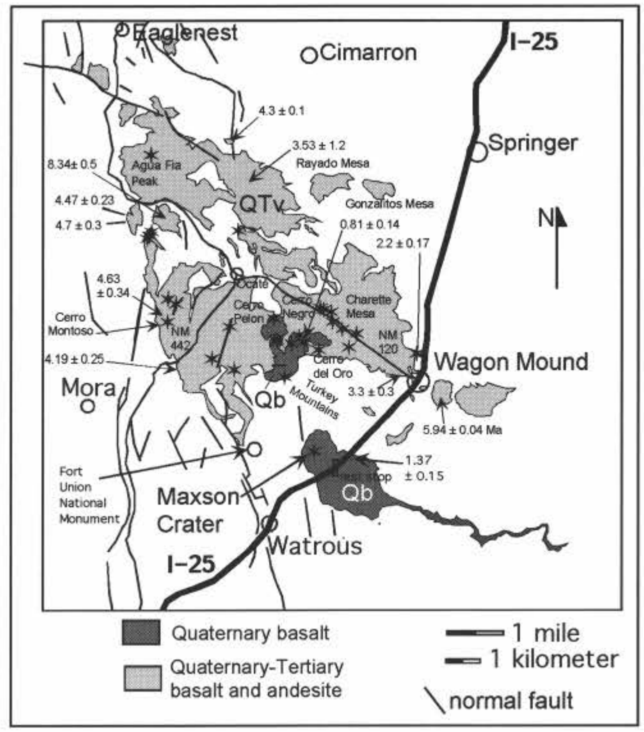

FIGURE 2. Geologic map of the Ocate volcanic field with currently known ages. Map redrafted and simplified from O'Neill and Mehnert (1988)

TABLE 2. Collected dates on rocks from the OVF.

Name of Feature	Age (technique)	Reference
Older Age Group (older than 5Ma)		
Sierra Montuoso	8.34 ± 0.50 (K-Ar)	O'Neill and Mehnert, 1998
Las Mesas del Conjelon (west mesa)	5.94 ± 0.40 (K-Ar)	O'Neill and Mehnert, 1998
Intermediate Age (5-4 Ma)		
Cerro Montoso	4.67 ± 0.32 (K-Ar)	O'Neill and Mehnert, 1998
Gonzalitos Mesa	4.52 ± 0. 34 (K-Ar)	O'Neill and Mehnert, 1998
Sawmill Ranch,	4.47 ± 0.23 (K-Ar)	O'Neill and Mehnert, 1998
S. of Agua Fria	4.7 ±0.3 (K-Ar)	Stormer, 1973
La Mesa	4.19 ± 0.25 (K-Ar)	O'Neill and Mehnert, 1998
El Cerro Colorado	4.12 ± 0.24 (K-Ar)	O'Neill and Mehnert, 1998
Urraca Mesa	4.3 ± 0.1 (K-Ar)	Hussey, 1971
Younger Age Group (younger than 4 Ma)		
White Peak on Ortega Mesa	3.53 ± 1.2 (K-Ar)	O'Neill and Mehnert, 1998
Santa Clara Mesa	3.3 ± 0.3 (K-Ar)	Stormer, 1973
Charette Mesa	3.07 ± 0.34 (K-Ar)	O'Neill and Mehnert, 1998
Vent NW of Wagon Mound	2.20 ± 0.17 (K-Ar)	O'Neill and Mehnert, 1998
Maxon Crater	1.37 ± 0.15 (K-Ar)	O'Neill and Mehnert, 1998
Cerro del Oro	0.81 ± 0.14 (K-Ar)	O'Neill and Mehnert, 1998

east of I-25, mark an apparent E-W fissure system that has been dated at 5.9 Ma. In general, these flows are aphanitic to porphyritic basalts containing both olivine and plagioclase phenocrysts. Chemically, they grade between calc-alkalic and tholeiitic.

Volcanism between 5 and 4 Ma

Volcanic rocks of the intermediate age group are abundant in the northern part of the OVF, including flows that cap Urraca and Fowler Mesas, in the NE, and Rayado and Gonzalitos Mesas, E-SE of the Cimarron Range. Most of the flows in and around Agua Fria Peak also appear to be of this age, as does the basalt cap of Gallina Mesa. In general, flows of this age group are generally olivine basalts that were erupted on an erosion surface that ranges in elevation from 3000 m south of the Cimarron Range to 2100 m on the adjacent Great Plains geographic province. Many of the vents associated with these flows are shield volcanoes: examples are Aspen Hill, Spruce Hill, Apache peak, and Agua Fria Peak. However, the intermediate age rocks are variable in chemistry, including andesite and dacite. Cerro Montoso, in the area of La Mesa, is a composite volcano. The cone is composed of scoria, volcanic breccia, and flow-banded andesite, with dacite flows emanating from its base. Geologic mapping of the basalt flows of El Cerro Colorado in Los Chupaderos Valley shows a high-angle normal fault that has offset flows of equivalent age by about 300 m.

Volcanism younger than 4 Ma

Basalts of the youngest age group are the most abundant flows in the OVF. This age group can, itself, be broken into three groups. The oldest consists of olivine basalt flows erupted onto gravel surfaces that are 50-75 m above the surrounding plains and are dated between 3.1 and 3.3 Ma. These include the flows that cap Charette Mesa and the upper flows of Ortega and Rivera Mesas. The next group consists of olivine basalt flows erupted onto gravel surfaces 15m above the surrounding plains. These include the flows from the vents named Cerrito Pelon and Cerro Negro, the flows of Le Febres area, and the flows from a small mesa north of Wagon Mound. One date of 2.2 Ma has been acquired for these flows. The youngest group of flows consists of olivine basalt with dates ranging from 0.8 to 1.4 Ma and erupted onto surfaces that are only slightly eroded and dissected. These include the flows of Cerro del Oro and its nearby vents, and Maxon Crater and its associated flows. The youngest flows in the field were erupted from the multiple Cerro del Oro scoria cone vents in the central part of Charette Mesa, northwest of Wagon Mound.

Maxon Crater (1.4 Ma) is a large basaltic shield volcano located about 12km south of Wagon Mound and west of I-25. Flows from Maxon flowed 90km eastward, through the canyon cut by the Mora River, to just beyond the confluence of the Mora and Canadian rivers, where the flows lie 100m below the rim of the canyon and 125m above the present level of the rivers.

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